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of wire were subjoined beyond it; and 5° when 550 miles were interposed between the battery and galvanometer, the same length, 110 miles, being subjoined. In like manner, when 220 miles were added beyond the galvanometer placed near the battery, the indication was 12°; precisely the same as when 440 miles were interposed and 220 added. So also when 330 miles were added, the deviation of the galvanometer was 18°; and 15° when 330 miles were interposed and 330 added. I have no doubt that the correspondence would have been closer had it not been for the fluctuations of the battery.

It would appear from this, that whatever be the length of wire attached to the insulated pole of a battery, it becomes charged to the same degree of tension throughout its entire extent; so that another insulated wire brought into connexion with its free extremity exhibits precisely the same phenomena, in kind and measure, as when it is brought into immediate connexion with a pole of the battery. Some important practical consequences flow from this conclusion, which I will not develope at present, as I have not yet had an opportunity of submitting them to the test of experiment.

April 19, 1855.

The LORD WROTTESLEY, President, in the Chair.

The Right Hon. Lord Hatherton was admitted into the Society.

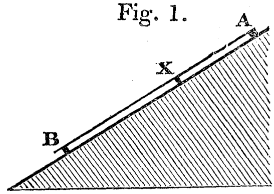
The following communications were read:—

I. "On the descent of Glaciers." By the Rev. HENRY MOSELEY, M.A., F.R.S., Corresponding Member of the Institute of France. Received March 15, 1855.

If we conceive two bodies of the same form and dimensions (cubes for instance), and of the same material, to be placed upon a uniform

horizontal plane, and connected by a substance which alternately extends and contracts itself, as does a metallic rod when subjected to variations of temperature, it is evident that by the extension of the intervening rod each will be made to recede from the other by the same distance, and, by its contraction, to approach it by the same distance. But if they be placed on an inclined plane (one being lower than the other), then when by the increased temperature of the rod its tendency to extend becomes sufficient to push the lower of the two bodies downwards, it will not have become sufficient to push the higher upwards. The effect of its extension will therefore be to cause the lower of the two bodies to descend whilst the higher remains at rest. The converse of this will result from contraction; for when the contractile force becomes sufficient to pull the upper body down the plane it will not have become sufficient to pull the lower up it. Thus, in the contraction of the substance which intervenes between the two bodies, the lower will remain at rest whilst the upper descends. As often, then, as the expansion and contraction is repeated the two bodies will descend the plane until, step by step, they reach the bottom.

Fig. 1.



Suppose the uniform bar AB placed on an inclined plane, and subject to extension from increase of temperature, a portion XB will descend, and the rest XA will ascend; the point X where they separate being determined by the condition that the force requisite to push XA up the plane is equal to that required to push XB down it.

Let AX$=x$, AB$=$L, weight of each linear unit $=u$, $i=$ inclination of plane, $\phi=$ limiting angle of resistance,

$$\therefore \quad ux = \text{ weight of AX},$$
$$u(\mathrm{L}-x) = \text{ weight of BX}.$$

Now, the force acting parallel to an inclined plane which is necessary to push a weight W up it, is represented by

$$\mathrm{W}\,\frac{\sin(\phi+i)}{\cos\phi}\,;$$

and that necessary to push it down the plane by

$$\mathrm{W}\,\frac{\sin(\phi-i)}{\cos\phi}\,;$$

$$\therefore \quad ux\frac{\sin(\phi+i)}{\cos\phi}=u(\mathrm{L}-ux)\frac{\sin(\phi-i)}{\cos\phi}$$

$$\therefore \quad x\{\sin(\phi+i)+\sin(\phi-i)\}=\mathrm{L}\sin(\phi-i)$$

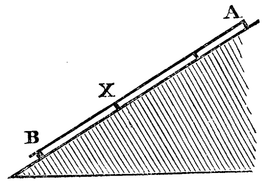
$$\therefore \quad 2x\sin\phi\cos i=\mathrm{L}\sin(\phi-i)$$

$$\therefore \quad x=\frac{1}{2}\mathrm{L}\frac{\sin(\phi-i)}{\sin\phi\cos i}$$

$$\therefore \quad x=\frac{1}{2}\mathrm{L}\left\{1-\frac{\tan i}{\tan\phi}\right\}.$$

When contraction takes place the converse of the above will be true. The separating point X will be such, that the force requisite to pull XB up the plane is equal to that required to pull AX down it. BX is obviously in this case equal to AX in the other.

Fig. 2.



Let λ be the elongation per linear unit under any variation of temperature; then the distance which the point B (see fig. 1) will be made to descend by this elongation

$$=\lambda.\overline{\mathrm{BX}}$$
$$=\lambda(\mathrm{L}-x)$$
$$=\frac{1}{2}\lambda\mathrm{L}\left(1+\frac{\tan i}{\tan\phi}\right).$$

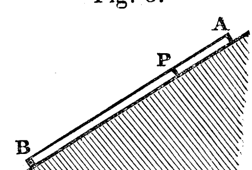
If we conceive the bar now to return to its former temperature, contracting by the same amount (λ) per linear unit; then the point B (fig. 2) will by this contraction be made to ascend through the space

$$\mathrm{BX}.\lambda=x\lambda$$
$$=\frac{1}{2}\mathrm{L}\lambda\left\{1-\frac{\tan i}{\tan\phi}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Total descent l of B by elongation and contraction is therefore determined by the equation

$$l=\mathrm{L}\lambda\frac{\tan i}{\tan\phi}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Fig. 3.



To determine the pressure upon a nail, driven through the rod at any point P fastening it to the plane.

It is evident that in the act of extension the part BP of the rod will descend the plane and the part AP ascend; and

conversely in the act of contraction; and that in the former case the nail B will sustain a pressure upwards equal to that necessary to cause BP to descend, and a pressure downwards equal to that necessary to cause PA to ascend; so that, assuming the pressure to be downwards, and adopting the same notation as before, except that AP is represented by ρ, AB by a, and the pressure upon the nail (assumed to be downwards) by P, we have in the case of extension

$$P = u\rho \frac{\sin(\phi+i)}{\cos\phi} - u(a-\rho)\frac{\sin(\phi-i)}{\cos\phi},$$

and in the case of contraction

$$P = u(a-\rho)\frac{\sin(\phi+i)}{\cos\phi} - u\rho\frac{\sin(\phi-i)}{\cos\phi}.$$

Reducing, these formulæ become respectively

$$P = \frac{u}{\cos\phi}\left\{2\rho\sin\phi\cos i - a\sin(\phi-i)\right\} \quad . \quad . \quad . \quad (3)$$

$$P = \frac{u}{\cos\phi}\left\{a\sin(\phi+i) - 2\rho\sin\phi\cos i\right\} \quad . \quad . \quad . \quad (4)$$

My attention was first drawn to the influence of variations in temperature to cause the descent of a lamina of metal resting on an inclined plane, by observing, in the autumn of 1853, that a portion of the lead which covers the south side of the choir of the Bristol Cathedral, which had been renewed in the year 1851, but had not been properly fastened to the ridge beam, had descended bodily 18 inches into the gutter; so that if plates of lead had not been inserted at the top, a strip of the roof of that length would have been left exposed to the weather. The sheet of lead which had so descended measured, from the ridge to the gutter, 19 feet 4 inches and along the ridge 60 feet. The descent had been continually going on, from the time the lead had been laid down. An attempt made to stop it by driving nails through it into the rafters had failed. The force by which the lead had been made to descend, whatever it was, had been found sufficient to draw the nails*. As the pitch of

* The evil was remedied by placing a beam across the rafters near the ridge, and doubling the sheets round it, and fixing their ends with spike nails.

the roof was only $16\frac{1}{2}^\circ$, it was sufficiently evident that the weight of the lead alone could not have caused it to descend. Sheet lead, whose surface is in the state of that used in roofing, will stand firmly upon a surface of planed deal when inclined at an angle of 30°*, if no other force than its weight tends to cause it to descend. The considerations which I have stated in the preceding articles led me to the conclusion that the daily variations in the temperature of the lead, exposed as it was to the action of the sun by its southern aspect, could not but cause it to descend considerably, and the only question which remained on my mind was, whether this descent could be so great as was observed. To determine this I took the following data:—

Mean daily variation of temperature at Bristol in the month of August, assumed to be the same as at Leith (Kaemtz, Meteorology, by Walker, p. 18), 8°·21 Cent.

Linear expansion of lead through 100° Cent. ·0028436.

Length of sheets of lead forming the roof from the ridge to the gutter 232 inches.

Inclination of roof 16° 32′.

Limiting angle of resistance between sheet lead and deal 30°.

Whence the mean daily descent of the lead, in inches, in the month of August, is determined by equation (2) to be

$$l = 232 \times \frac{8^\circ{\cdot}21}{100} \times {\cdot}0028436 \times \frac{\tan 16^\circ\ 32'}{\tan 30^\circ}$$

$$l = {\cdot}027848 \text{ inches.}$$

The average daily descent gives for the whole month of August a descent of ·863288. If the average daily variation of temperature of the month of August had continued throughout the year, the lead would have descended 10·19148 inches every year. And in the

* This may easily be verified. I give it as the result of a rough experiment of my own. I am not acquainted with any experiments on the friction of lead made with sufficient care to be received as authority in this matter. The friction of copper on oak has, however, been determined by General Morin to be 0·62, and its limiting angle of resistance 31° 48′; so that if the roof of Bristol Cathedral had been inclined at 31° instead of 16°, and had been covered with sheets of copper resting on oak boards, instead of sheets of lead resting on deal, the sheeting would not have slipped by its weight only.

two years from 1851 to 1853 it would have descended 20·38296 inches. But the daily variations of atmospheric temperature are less in the other months of the year than in the month of August. For this reason, therefore, the calculation is in excess. For the following reasons it is in defect:—1st, the daily variations in the temperature of the lead cannot but have been greater than those of the surrounding atmosphere. It must have been heated above the surrounding atmosphere by radiation from the sun in the day-time, and cooled below it by radiation into space at night. 2ndly. One variation of temperature only has been assumed to take place every twenty-four hours, viz. that from the extreme heat of the day to the extreme cold of the night; whereas such variations are notoriously of constant occurrence during the twenty-four hours. Each cannot but have caused a corresponding descent of the lead, and their aggregate result cannot but have been greater than if the temperature had passed uniformly (without oscillations backwards and forwards) from one extreme to the other.

These considerations show, I think, that the causes I have assigned are sufficient to account for the fact observed. They suggest, moreover, the possibility that results of importance in meteorology may be obtained from observing with accuracy the descent of a metallic rod thus placed upon an inclined plane. That descent would be a measure of the aggregate of the changes of temperature to which the metal was subjected during the time of observation. As every such change of temperature is associated with a corresponding development of mechanical action under the form of work*, it would be a measure of the aggregate of such changes and of the work so developed during that period; and relations might be found between measurements so taken in different equal periods of times, successive years for instance, tending to the development of new meteorological laws.

The following are the results of recent experiments† on the expansion of ice:—

* Mr. Joule has shown (Phil. Trans. 1850, Part I.) that the quantity of heat capable of raising a pound of water by 1° Fahr. requires for its evolution 772 units of work.

† Vide Archiv f. Wissenchaftl. Kunde v. Russland, Bd. vii. S. 333.

Linear expansion of ice for an interval of 100° of the Centigrade thermometer.

0·00524, Schumacher.
0·00513, Johrt.
0·00518, Moritz.

Ice, therefore, has nearly twice the expansibility of lead, so that a sheet of ice would, under similar circumstances, have descended a plane similarly inclined, twice the distance that the sheet of lead referred to in the preceding article descended. Glaciers are, on an increased scale, sheets of ice placed upon the slopes of mountains, and subjected to atmospheric variations of temperature throughout their masses by variations in the quantity and the temperature of the water, which flowing from the surface everywhere percolates them. That they must from this cause descend into the valleys is therefore certain. That portion of the Mer de Glace of Chamouni which extends from Montanvert to very near the origin of the Glacier de Léchaud, has been accurately observed by Professor James Forbes*. Its length is 22,600 feet, and its inclination varies from 4° 19′ 22″ to 5° 5′ 53″. The Glacier du Géant, from the Tacul to the Col du Géant, Professor Forbes estimates (but not from his own observations, or with the same certainty) to be 24,700 feet in length, and to have a mean inclination of 8° 46′ 40″.

According to the observations of De Saussure, the mean daily range of Reaumur's thermometer in the month of July, at the Col du Géant, is 4°·257†, and at Chamouni 10°·092. The resistance opposed by the rugged channel of a glacier to its descent cannot but be different at different points and in respect to different glaciers. The following passage from Professor Forbes's work contains the most authentic information I am able to find on this subject. Speaking of the Glacier of la Brenva, he says, "The ice removed, a layer of fine mud covered the rock, not composed however alone of the clayey limestone mud, but of sharp sand derived from the granitic moraines of the glacier, and brought down with it from the opposite side of the valley. Upon examining the face of the ice removed from contact with the rock, we found it *set* all over

* Travels through the Alps of Savoy. Edinburgh, 1843.

† Quoted by Professor Forbes, p. 231.

with sharp angular fragments, from the size of grains of sand to that of a cherry, or larger, of the same species of rock, and which were so firmly fixed in the ice as to demonstrate the impossibility of such a surface being forcibly urged forwards without sawing and tearing any comparatively soft body which might be below it. Accordingly, it was not difficult to discover in the limestone the very grooves and scratches which were in the act of being made at the time by the pressure of the ice and its contained fragments of stone." (Alps of the Savoy, pp. 203–4.) It is not difficult from this description to account for the fact that small glaciers are sometimes seen to lie on a slope of 30° (p. 35). The most probable supposition would indeed fix the limiting angle of resistance between the rock and the under surface of the ice, set all over, as it is described to be, with particles of sand and small fragments of stone, at about 30°, that being nearly the slope at which calcareous stones will rest on one another. If we take then 30° to be the limiting angle of resistance between the under surface of the Mer de Glace and the rock on which it rests, and if we assume the same mean daily variation of temperature (4·257 Reaumur, or 5·321 Centigrade) to obtain throughout the length of the Glacier du Géant, which De Saussure observed in July at the Col du Géant; if, further, we take the linear expansion of ice at 100° Centigrade to be that (·00524) which was determined by the experiments of Schumacher; and, lastly, if we assume the Glacier du Géant to descend as it would if its descent were unopposed by its confluence with the Glacier de Léchaud, we shall obtain, by substitution in equation (2) for the mean daily descent of the Glacier du Géant at the Tacul, the formula—

$$l = 24700 \times 5{\cdot}321 \times \frac{{\cdot}00524}{100} \times \frac{\tan 8^\circ 46'}{\tan 30^\circ}$$

$$l = 1{\cdot}8395 \text{ feet.}$$

The actual descent of the glacier in the centre was 1·5 foot. If the Glacier de Léchaud descended at a mean slope of 5°, singly in a sheet of uniform breadth to Montanvert without receiving the tributary glacier of the Talèfre, or uniting with the Glacier du Géant, its diurnal descent would be given by the same formula, and would be found to be ·95487 foot. Reasoning similarly with reference to the Glacier du Géant, supposing it to have continued its course singly from the Col du Géant to Montanvert without confluence with the

Glacier de Léchaud, its length being 40,420 feet, and its mean inclination $6^{\circ}\ 53'$, its mean diurnal motion l at Montanvert would, by formula (2) have been 2·3564 feet*. The actual mean daily motion of the united glaciers, between the 1st and the 28th July, was Montanvert (Forbes's 'Alps of the Savoy,' p. 140),—

Near the side of the glacier	1·441 foot.
Between the side and the centre ..	1·750 foot.
Near the centre	2·141 feet.

The motion of the Glacier de Léchaut was therefore accelerated by their confluence, and that of the Glacier du Géant retarded. The former is dragged down by the latter.

I have had the less hesitation in offering this solution of the mechanical problem of the motion of glaciers, as those hitherto proposed are confessedly imperfect. That of De Saussure, which attributes the descent of the glacier simply to its weight, is contradicted by the fact that isolated fragments of the glacier stand firmly on the slope on which the whole nevertheless descends; it being obvious that if the parts would remain at rest separately on the bed of the glacier, they would also remain at rest when united.

That of Professor J. Forbes, which supposes a viscous or semifluid structure of the glacier, is not consistent with the fact that no viscosity is to be traced in its parts when separated. They appear as solid fragments, and they cannot acquire in their union properties in this respect which individually they have not.

Lastly, the theory of Charpentier, which attributes the descent of the glacier to the daily congelation of the water which percolates it, and the expansion of its mass consequent thereon, whilst it assigns a cause which, so far as it operates, cannot, as I have shown, but cause the glacier to descend, appears to assign one inadequate to the result; for the congelation of the water which percolates the glacier does not, according to the observations of Professor Forbes †, take place at all in summer more than a few inches from the surface. Nevertheless it is in the summer that the daily motion of the glacier is the greatest.

* On the 1st of July, the centre of the actual motion of the Mer de Glace at Montanvert was 2·25 feet.

† Travels in the Alps.

The following remarkable experiment of Mr. Hopkins of Cambridge*, which is considered by him to be confirmatory of the sliding theory of De Saussure as opposed to De Charpentier's dilatation theory, receives a ready explanation on the principles which I have laid down in this note. It is indeed a necessary result of them. "Mr. Hopkins placed a mass of rough ice, confined by a square frame or bottomless box, upon a roughly chiselled flag stone, which he then inclined at a small angle, and found that a slow but uniform motion was produced, when even it was placed at an inconsiderable slope." This motion, which Mr. Hopkins attributed to the dissolution of the ice in contact with the stone, would, I apprehend, have taken place if the mass had been of lead instead of ice; and it would have been but about half as fast, because the linear expansion of lead is only about half that of ice.

II. "Reply of the President and Council of the Royal Society to an application from the Lords of the Committee of Privy Council for Trade, on the subject of Marine Meteorological Observations."

[This Letter was communicated to the Society in pursuance of a resolution of the Council. The Secretary explained that it had been drawn up by the Treasurer, Colonel Sabine, and submitted, before final adoption by the Council, to several Fellows of the Society specially conversant with the subjects to which it refers.]

Royal Society, Somerset House,
February 22, 1855.

Sir,—In the month of June last, the Lords of the Committee of the Privy Council for Trade caused a letter to be addressed to the President and Council of the Royal Society, acquainting them that their Lordships were about to submit to Parliament an estimate for an Office for the Discussion of the Observations on Meteorology, to

* I have quoted the above account of it from Professor Forbes's book, p. 419.